Magnetic Amplifier for Power Flow Control

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Project Objectives

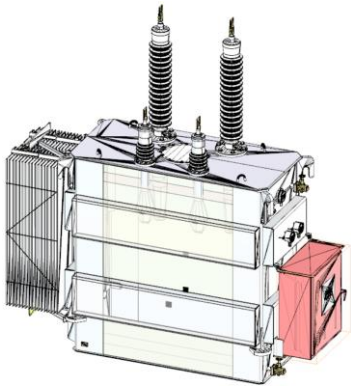
- Develop simple, robust, and efficient power flow control device (CVSR) based on magnetic amplifier principle

INNOVATIVE	HIGH PERFORMANCE	RELIABLE
• Novel use of existing technologies • Magnetic field used as control medium	• Large continuously variable reactance • Cost-effective for full power flow control	• Simple construction • Electrical isolation between power and control circuits

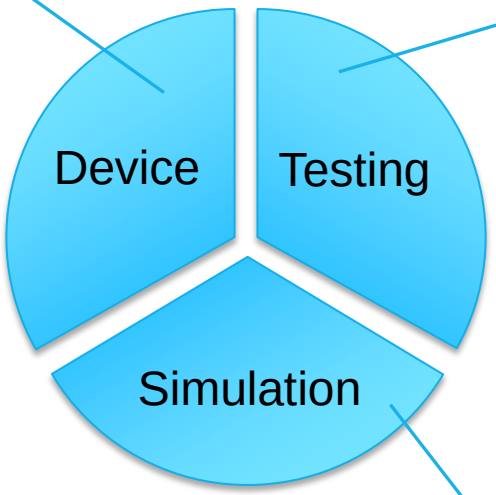
- Build transmission-level prototype for field demonstration, based on design and testing experiences from laboratory prototypes
- Conduct system integration and benefit studies to prepare for system-wide deployment
- Expand the functionality of the device beyond steady state operation (damp low-frequency oscillations, limit fault currents)

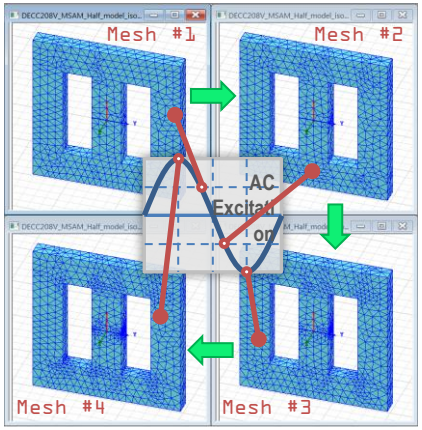
Transmission-level Prototype

Completion of the design and building of a 115kV, 1500 A CVSR to be installed for field demonstration



Conducted two factory tests to validate parameters and performance of the prototype

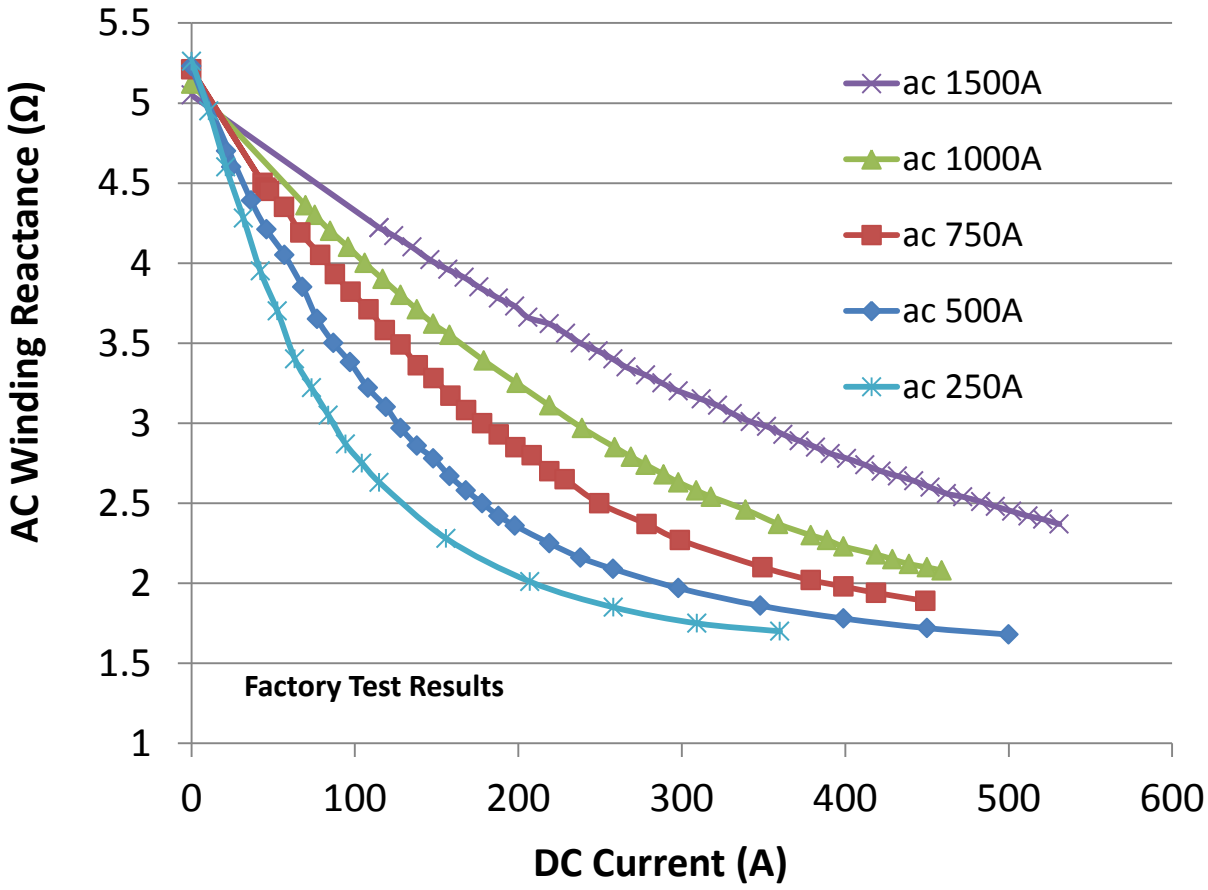




Improved FEA simulation by using a new approach to create reliable mesh for strong nonlinear magnetization

Reactance Characteristics

- Regulation curves obtained from two factory tests

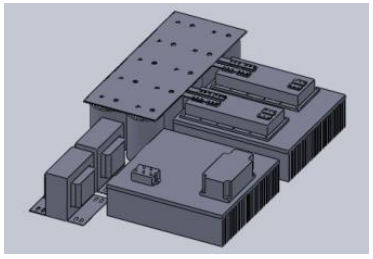


DC Converter & Control System

- Upgraded current and voltage ratings
- Tolerant to surge and other transient conditions from AC and DC sides; self protect during abnormal and fault conditions
- Capable of continuous communication and status updates with the system-level controller; without control power
- Suitable for outdoor operation; low maintenance requirements







DC Converter Strategy and Status

Focus on meeting the performance requirements. Three versions of hardware:

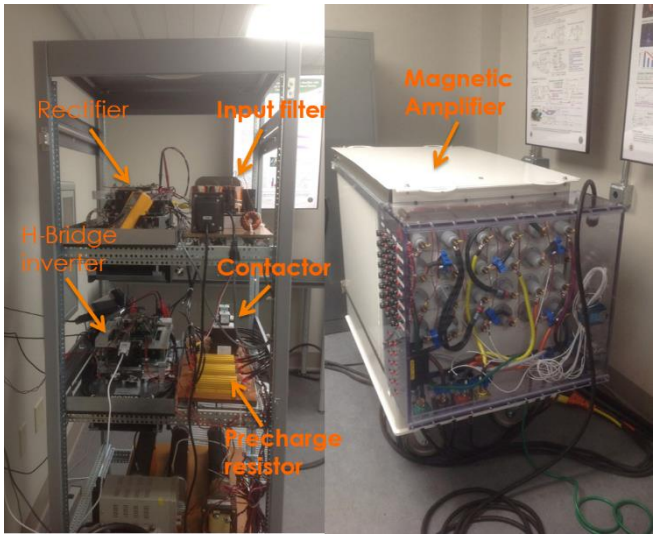
1) Use a down scaled lab DCC (HW1) system based on commercial products to develop software, control and protection (development complete, in use for control software and hardware testing)

2) Build a full scale DCC (HW2) for factory testing focusing on operation functionalities (under assembly and testing)

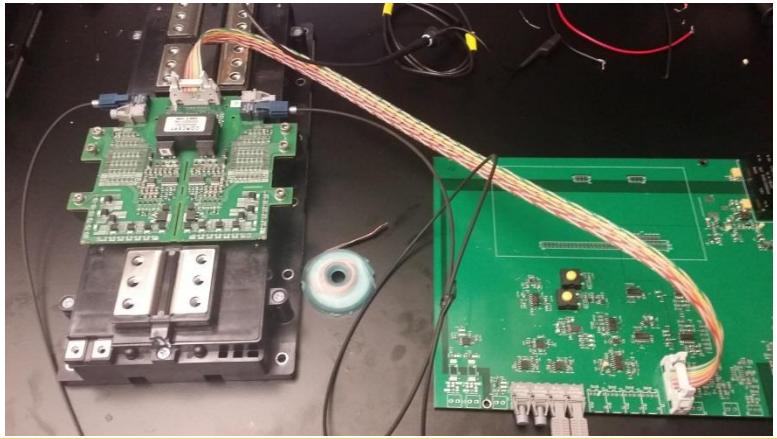
3) Build the full converter system (HW3) for field commissioning in 2015 with all functionalities and capabilities (started on key cooling and enclosure design, may need adjustments based on HW2 testing)

DC Converter Development

HW1 Lab Test Setup



HW2 Busbar Assembly



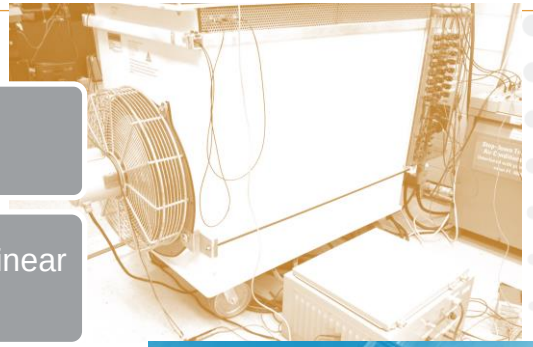
HW2 Gate Drive and Interface Boards under Test

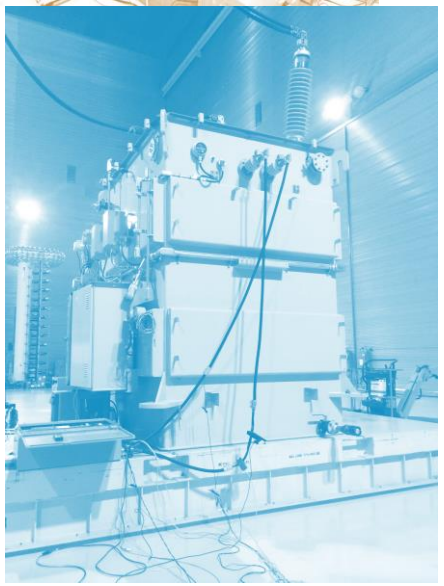
Field Demonstration

- Finishing the factory tests for the reactor
- Completion of the DCC
- Integration of the reactor control system and DCC
- Installation and conducting the field test/operation

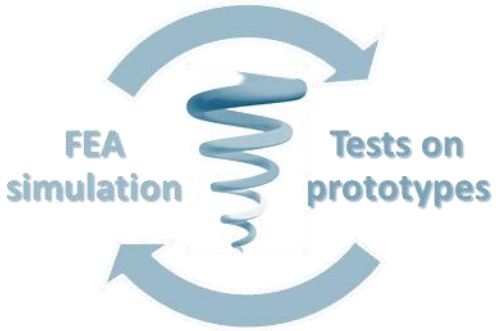
BPA's Sacajawea S/S
Walla Wall Co, WA

What has been done and learned?



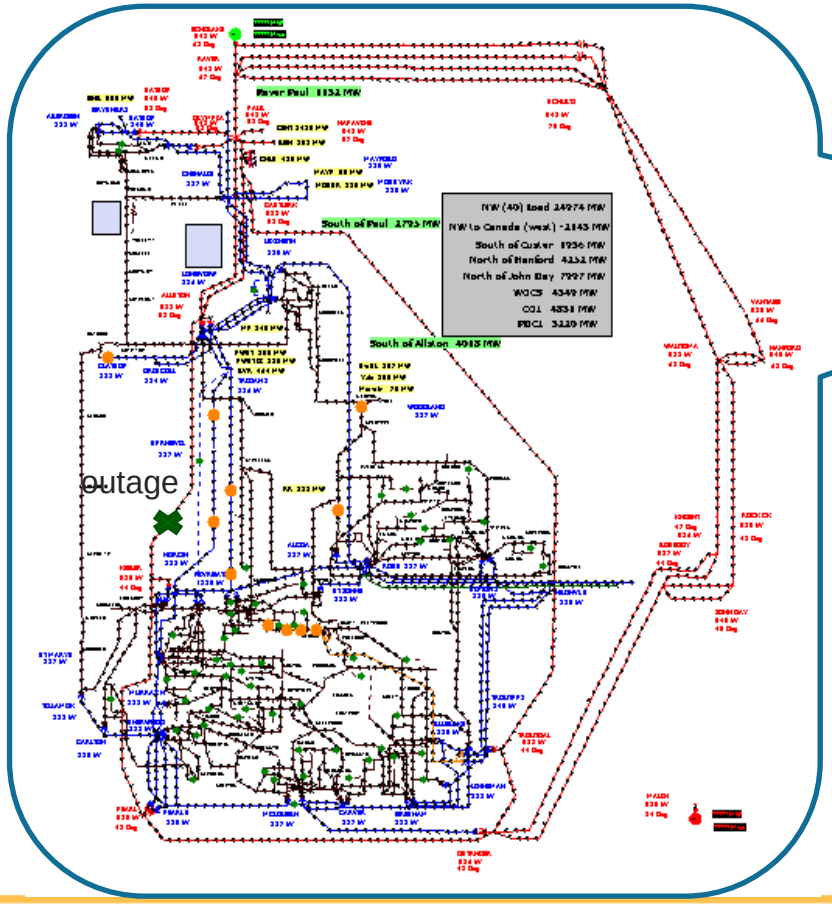


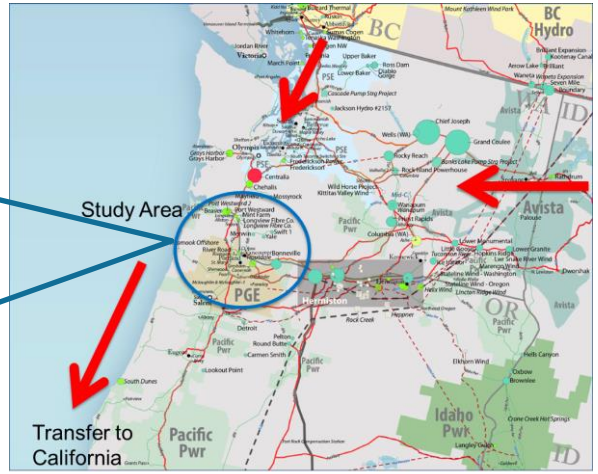
- **Concept Validation**
  - **Theoretical**
    - Simple model to initially validate the idea
    - FEA simulation used to understand the nonlinear operation and design the prototype
  - **Practical**
    - Four laboratory-scale prototypes designed, built and tested to help achieve different research goals
    - A single-phase transmission-level prototype designed, built and tested to prepare for field demonstration
- **Approach**
  - **Iterative**
    - FEA
    - Co-simulation
    - Test



Grid Integration - Benefit Study

- Congestion relief under certain power system contingencies
- Shift power from overloaded lines to the underloaded path





No. of lines	Pre-contingency	Post-contingency	Optimization (k_f=5)
1	93.78%	105.65%	100%
2	92.30%	103.19%	100%
3	91.87%	103.19%	99.34%

Technology-to-Market

- Exclusive license to SPX/Waukesha TS
- Commercial Product Initiative – 7 stages
  - Statement of needs
  - Validation of needs
  - Plan and approval
  - Product design and validation
  - Operational readiness manufacturing
  - Commercial readiness
  - Release and audit

Post ARPA-E Goals

- Promote large-scale deployment of CVSR through system benefit studies
- Facilitate the commercialization through development of installation & operation procedures and training materials
- Investigate additional capabilities of the device with different control schemes (“firmware upgrades”)
- Improve further the design for a smaller, lighter, and cheaper unit (“hardware upgrades”)

Conclusions

- Factory tests help further understand the operational characteristics of the CVSR and prepare for the field demonstration
- Iterative modeling-simulation-testing process improved the device and the models
- Three hardware generations of the DC converter and control system
- Initial benefits in congestion relief, other applications to follow
- Exclusive manufacturing by SPX/Waukesha TS

Thank You!

This endeavor would not have been possible without the support from